



THE START OF RUN II at CDF

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After a hiatus of almost 6 years and an extensive upgrade, Tevatron, the world largest proton-antiproton collider, has resumed the operation for the so called RUN II. In this paper we give a brief overview of the many new features of the Tevatron complex and of the upgraded CDF experiment, and show the presently achieved detector performances as well as highlights of the RUN II physics program in the beauty and electroweak sector.

1 Tevatron and RUN II

The Tevatron at the Fermi National Accelerator Laboratory (Fermilab) with its 980 GeV proton-antiproton beams is currently the highest energy collider in the world. It has resumed operation in April 2001 after a major upgrade. The earlier run terminated in 1996 after delivering a luminosity of $\approx 110 \text{ pb}^{-1}$ to both CDF and D0 experiments that allowed a successful physics program ranging from the discovery of the top quark to the measurements of W and top masses as well as the first evidence for CP violation in B decays.

The present run (RUN IIa) aims at an integrated luminosity of 2fb^{-1} by the end of 2004, a factor 20 more than the entire RUN I. To this end the Tevatron accelerator complex underwent a substantial upgrade. The Main Ring was dismantled and a new injector for Tevatron has been built in a separate tunnel, the Main Injector. It will increase the production rate of antiprotons, a key factor for luminosity improvement, by at least a factor three. Another major boost in luminosity is expected from the new Recycler Ring, a permanent magnet storage ring housed in the same tunnel as the Main Injector. At the end of a physics store the remaining 75% of the antiproton beam will be decelerated to 8 GeV and stored in the Recycler for later use. This component of the accelerator complex is still in the commissioning stage and will be brought in to operation in 2003.

In the present configuration Tevatron is running with 36 bunches of protons and antiprotons which collide at the interaction regions every 396 ns. In a later stage there will be 108 bunches with 132 ns interbunch separation. Increasing the number of bunches with respect to the RUN I configuration allows to keep essentially unchanged the luminosity per bunch and hence the number of events per crossing thus retaining a relatively clean environment for offline reconstruction, at the cost of completely redesigning detector DAQ (see 2.1).

Fermilab also plans to extend the lifetime of the current experiments with a further run (RUN IIb) scheduled to begin in the second half of 2005 allowing for a 6 month shutdown for accelerator and detector upgrade. 15 fb^{-1} will be collected by 2008 with the primary focus being the search for Higgs Boson in the 115–190 GeV/ c^2 range.

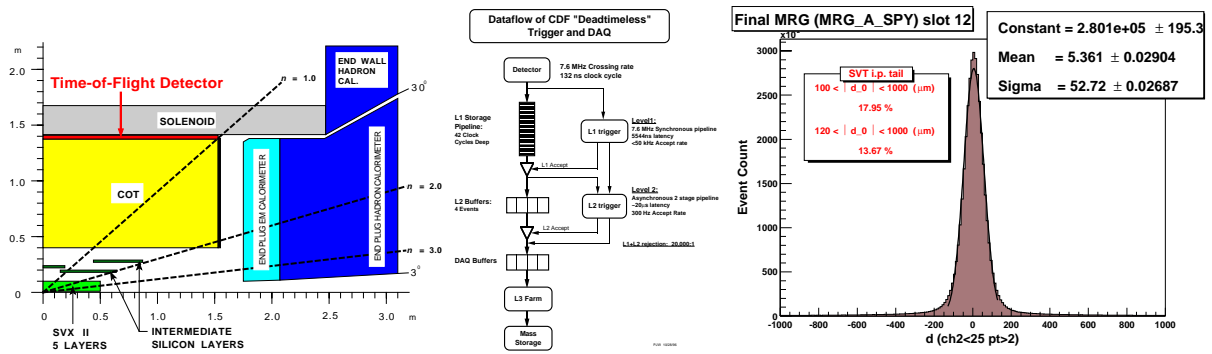


Figure 1: (Left) Quadrant of the CDF detector tracking volume with the plug calorimeter; (Center) Trigger and DAQ flow chart; (Right) online SVT impact parameter resolution (includes beam width contribution of $\approx 30\mu m$)

The first year of the Tevatron operation has been largely devoted to studies on the machine and the detectors. As of this writing (May 2002) typical peak luminosity of Tevatron is $2 \cdot 10^{31} cm^{-2} s^{-1}$ and CDF is collecting between 2 and 3 pb^{-1} on tape per week. Tevatron luminosity is expected to increase substantially after more cooling power will be installed during summer shutdown. For the end of 2002 CDF expects to have nearly 100 pb^{-1} on tape usable for most of the analysis; presently (May 2002) this figure is 25 pb^{-1} .

2 The CDF detector for RUN II

The CDF detector upgrade addressed the issues related to the shorter bunch crossing time of RUN II with a completely rebuilt DAQ and Trigger system, new Plug calorimeters, and a faster drift chamber¹. The vertex detector was completely rebuilt with a larger silicon detector to improve tracking efficiency and enhance b-tagging at larger rapidity. Triggering at Level 2 on displaced vertex from heavy flavour decays became possible with the Silicon Vertex Tracker (SVT). Particle Identification, previously based only on charged particles dE/dX measured in the drift chamber, has been complemented with the Time Of Flight (TOF).

2.1 Trigger and DAQ

All front end electronics have been completely redesigned to cope with the shorter interbunch separation and the “deadtimeless” design of the new three stage trigger system. At Level 1 track segments in the muon detector, calorimeter cell energies and tracks reconstructed in the drift chamber by the eXtremely Fast Tracker (XFT) processor are used to trigger on tracks, electron, muons, jets and missing energy. A synchronous pipelined readout allows a latency for Level1 decision of $5.5\mu s$ with 50 KHz maximum bandwidth into the Level 2. At this stage 4 alpha processors with a buffered readout refine the trigger decision using further information from the SVT processor (see 2.3), the electromagnetic shower max detector, the calorimeters and the muon detectors. There is a maximum bandwidth of 300 Hz towards the L3 trigger which is realized as a farm of commodity PC’s running a specialized version of the offline reconstruction program for the final decision. Events passing L3 requirements are written to mass storage with a maximum rate of 75 Hz or ~ 20 MB/s. The DAQ system is performing well and all the triggers foreseen for RUN II have been implemented by February 2002.

2.2 Tracking

CDF has built a new integrated tracking system combining a large drift chamber (COT) and three silicon detectors; L00, SVXII and ISL (fig. 1). The COT has a faster drift time with respect

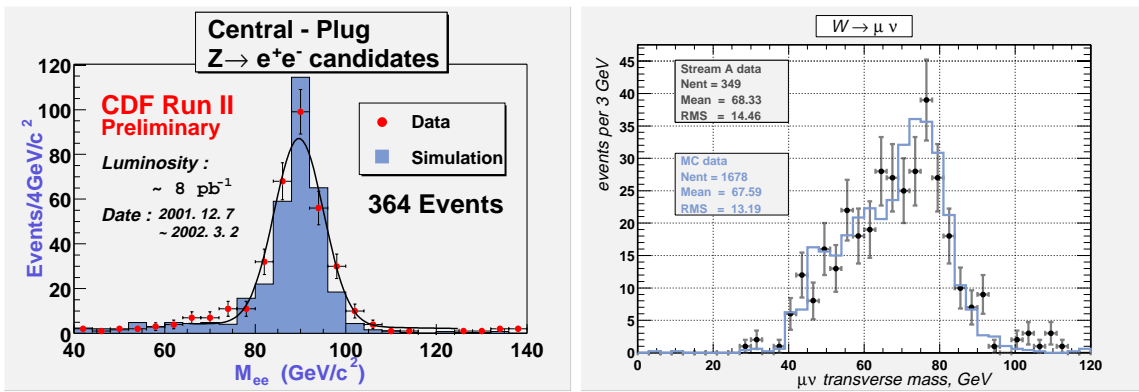


Figure 2: (Left) $Z \rightarrow e^+e^-$, with e^+ or e^- in the new plug; (Right) Transverse mass for $W \rightarrow \mu\nu$ events

to the RUN I detector and a more robust design for measuring tracks in the r-z plane. The combined L00, SVXII and ISL detectors provide 7 high precision points in the central rapidity region (8 in the high η region $1 < |\eta| < 2$). All systems but L00 have double sided sensors. L00 is the closest to the beam with just 1.6 cm radial distance from the center of the beam line. The outer ISL layer provides measurements at 28 cm radial distance, thus allowing accurate track reconstruction using only silicon detectors in the forward region $1 < |\eta| < 2$) where the COT acceptance rapidly decreases. Expected transverse momentum resolution is $\sigma_{p_t}/p_t^2 < 0.1\%$ and better than $30 \mu\text{m}$ for $p_t > 1 \text{ GeV}$ is expected for impact parameter. Currently L00 is still under commissioning and is not yet used in the reconstruction as is the central part of the ISL system. SVXII instead has more than 90% of its individual silicon detectors regularly functioning. Alignment and calibration of the detector are currently in progress. Nevertheless already with a first pass attempt at determining internal alignment, measured performances confirm expectations. Resolution on impact parameter for tracks from prompt J/ψ muons have been measured² to be $26 \mu\text{m}$ for $p_t > 2.2 \text{ GeV}$.

2.3 SVT

The SVT³ receives silicon detector raw data after each L1 accept. It performs pattern recognition inside the SVXII and L00 systems and associates silicon hits with tracks from the XFT to fit track parameters in the transverse plane in less than $20 \mu\text{s}$. The resolution on SVT impact parameter is expected to be similar to that of the offline reconstructed track thus allowing triggering on displaced vertex from Heavy Flavour decays. This is the first such device ever built for an hadron collider. The commissioning of the system was quickly successful and first data triggered by the SVT was taken as early as October 2001⁴. SVT is regularly part of the CDF trigger since February 2002. To date, nearly 10 pb^{-1} has been integrated with the SVT trigger that currently requires two tracks with opposite charge and impact parameter greater than $100 \mu\text{m}$. The currently achieved resolution on impact parameter is on average $52 \mu\text{m}$ including a beam width contribution of $\approx 30 \mu\text{m}$ as shown in fig. 1. This corresponds to $40 \approx \mu\text{m}$ resolution to be compared to $35 \mu\text{m}$ design. The level of the tails of the SVT impact parameter distribution, which drives the trigger rate, is around 15%. Both these figures will improve when better alignment and calibration of the detector will be available.

2.4 Plug calorimeters

The endplug calorimeter system has been entirely rebuilt for RUN II, mainly because the gas detectors of the RUN I calorimeters were not fast enough for the new timing constraint. Moreover

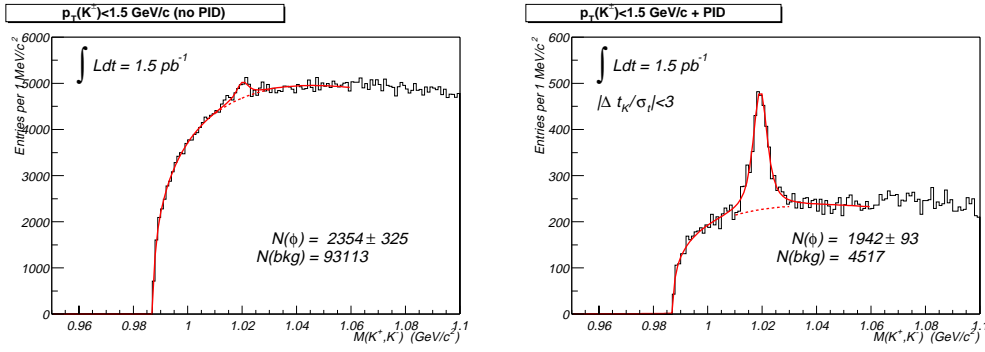


Figure 3: Example of Kaon identification in CDF with the new TOF detector to extract a $\phi \rightarrow K^+ K^-$ signal

the new detector, built with scintillating tiles as active medium, has a better sampling fraction and a better rapidity coverage ($|\eta| < 3.6$) than the old plugs. The system is operating reliably and calibrations are under way. A clean signal of $Z \rightarrow e^+ e^-$ where one of the electrons is detected in the plug calorimeters has been successfully reconstructed and is shown in fig. 2.

2.5 TOF

The Time Of Flight detector is composed of 216 bars of fast plastic scintillator of approximately 4x4 cm section and 280 cm length, placed in the space between the COT and the solenoid, and readout by 19 stage Hamamatsu fine mesh phototubes. The design resolution of the TOF detector is 100 ps that gives a better than 2σ π/K separation for $p_t < 1.6$ GeV. The TOF detector needs very careful calibrations to reach the desired performance, that currently are not yet finalized. The present measured resolution is 110 ps, allowing e.g. a clean separation of a $\phi \rightarrow K^+ K^-$ signal from the combinatorial background as illustrated in fig. 3.

3 First signals from RUN II data

Data taken in the first year of operation have been extremely useful to finish commissioning the detector and trigger. By the start of 2002 CDF has essentially completed this task and is now collecting physics quality data. Several hundreds W and Z events in both the electron and muon channels were cleanly reconstructed as early as fall 2001 (fig. 2), and were extremely valuable for detector commissioning and calibration.

With the dimuon trigger clean samples of J/ψ and ψ' were collected. This trigger has a substantially increased acceptance with respect to the RUN I configuration, and the expected increase in event yield has been observed in RUN II data. The width of the peaks are consistent with expectation too, and a preliminary attempt at measuring inclusive b lifetime using $b \rightarrow J/\psi X$ events gives already results consistent with world average making us confident on the quality of the detector and of its present alignment.

The ability to trigger on displaced vertex through the SVT is the most important novelty for b-physics in CDF. It was thus very important that clean signals of charm mesons were quickly established in the first data (less than 1 pb^{-1}) collected with this trigger. In fig. 4 peaks from the decays $D^0 \rightarrow K\pi$, $D^{*+} \rightarrow D^0\pi^+$ and $D_s \rightarrow \phi\pi^+ \rightarrow K^+K^-\pi^+$ are shown. No particle identification is yet used in the analysis as well as the 3D capability of the silicon detectors, signal extraction thus rely only on mass separation. Nevertheless very encouraging signal to noise ratios were obtained just repeating offline the trigger selections, as an example a $S/B > 3$ was obtained on the $D^0 \rightarrow K\pi$ peak. This was an extremely positive finding suggesting that despite hostile hadronic environment relatively clean sample of b hadrons will eventually be

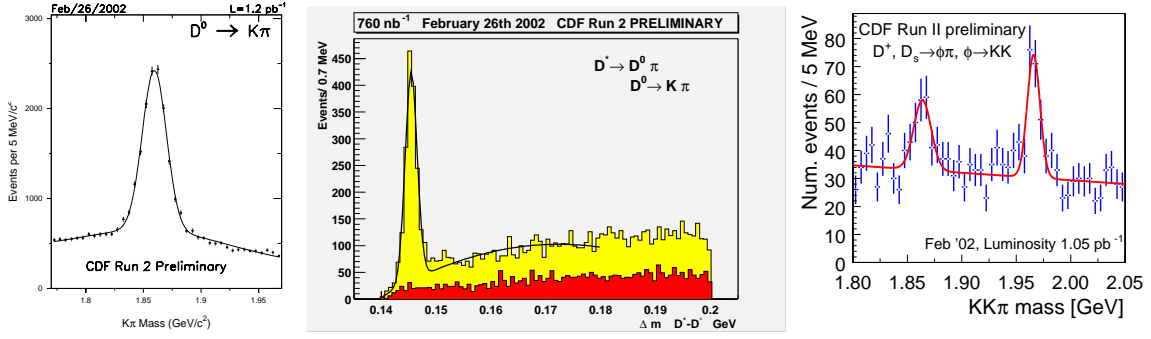


Figure 4: Charm meson peaks in the displaced vertex trigger. From left to right: $M_{K\pi}$ for $D^0 \rightarrow K\pi$; ΔM for $D^{*+} \rightarrow D^0 \pi^+$; $M_{K\pi}$ for $D_s \rightarrow \phi \pi^+ \rightarrow K^+ K^- \pi^+$ and the identical Cabibbo suppressed D^+ decay

reconstructed in the SVT triggers, and that it will be possible to keep the QCD background at a manageable level. Moreover given the measured yields of charm mesons (e.g. ≈ 8 nb for D^0) CDF is soon expected to collect samples bigger than those presently collected at the B factories. These data will be used for unique measurements of charm production in $p\bar{p}$ collisions and may possibly lead to competitive measurements of charm mixing and CP violation parameters.

4 Physics prospects in RUN IIa

4.1 B physics

Tevatron and the CDF detector offer unique opportunities for studying all species of b hadrons taking advantage of the huge cross section for b production in $p\bar{p}$ collision at $\sqrt{s} = 2$ TeV. Beside the spectroscopy and lifetime measurement for a large number of b hadrons, including e.g. B_c , CDF can put significant new constraints on the CKM parameter space.

Estimates⁵ based on extrapolation of RUN I data and expected performances of the new trigger and detectors indicate that a very competitive measurement of $\sin(2\beta)$ through the observation of the time dependent asymmetry of B^0 and \bar{B}^0 in CP states will be possible with RUN IIa luminosity. The expected error with 2fb^{-1} of integrated luminosity is 0.05 using only the “golden” mode $B^0(\bar{B}^0) \rightarrow J/\psi K_s^0$ with the $J/\psi \rightarrow \mu^+ \mu^-$. The key factors in this measurement are the accumulation of large samples of these decays and the effective power of the experiment in tagging the initial flavour of the B meson. This estimate is based on the expected 20000 $B^0(\bar{B}^0) \rightarrow J/\psi K_s^0$ decays that will be collected by CDF in RUN II taking into account the increased acceptance of the muon detectors and the lower p_t thresholds of the new trigger. With the RUN II detector CDF expect a combined ϵD^2 (the product of the tagging efficiency ϵ and the dilution factor $D = 1 - 2w$, where w is the wrong tagging probability) of 9.1%⁵. The factor 2 increase over the RUN I analysis⁶ is due in part to the extended acceptance for tracks of the new integrated tracking, which improve the performance of the Jet-charge tag, and in part to the introduction of the Opposite Side Kaon tag with the new TOF detector⁷.

Of particular importance in constraining the CKM matrix is the measurement of the mixing parameter $x_s = \Delta m_s / \Gamma$ in B_s flavour oscillation. The Standard Model fit to world data prefer for x_s the range $22.3 < x_s < 31.3$, while the present combined world lower limit on $\Delta m_s > 14.9\text{ps}^{-1}$ @ 95% C.L.⁸. In addition to the usual semileptonic mode, CDF will collect large samples of completely reconstructed hadronic decays of B_s with the SVT trigger that will be extremely valuable for the oscillation measurement especially if the x_s parameter turns out to be greater than 30. In fact the superior proper time resolution achievable in completely reconstructed modes, combined with the excellent impact parameter resolution of the L00 silicon detector, will allow a 5σ measurement with RUN II data up to $x_s \approx 60$ ⁵. As in the $\sin(2\beta)$ analysis also

in the the B_s mixing the new TOF detector plays a key role, greatly improving the effective tagging efficiency of the experiment, with the Same Side Kaon tag which correlates the charge of the Kaon produced in association with $B_s(\bar{B}_s)$ in the hadronization process with its initial flavour⁷.

4.2 High P_t physics

RUN II has the potential for very interesting results in the Electro-Weak and top sector.

The increase in luminosity and lepton acceptance will lead to statistical error of 20 MeV in the W mass measurement for both the electron and muon channel¹⁰. The most important source of systematics in the RUN I result⁹ was the lepton energy scale and resolution, as determined by $Z \rightarrow l^+l^-$ data, and was finally limited by the available statistics. This error is expected to scale with luminosity and be ~ 13 MeV with RUN IIa data. The leading error will then come from uncertainties in W production and decay models, also in part constrained by collider data, that will be ~ 15 MeV. A measurement for a single channel and single experiment with 40 MeV error seems feasible and is well matched to the present LEP2 precision as well as the current uncertainty in the indirect determination of M_W from Standard Model fit¹¹. For the W width an error of ~ 50 MeV is foreseen.

The top mass uncertainty will be greatly reduced in RUNII, with a statistical error of 1.7 GeV in the lepton + 2 b-tag sample alone. This is the channel with the greatest sensitivity to the top mass and will benefit from the improved b-tagging efficiency expected with RUN II detector. Jet energy scale uncertainty may be reduced using both $Z \rightarrow b\bar{b}$ events and reconstructing the W mass from jets in lepton + 2 b-tag top sample. The goal for RUN IIa is a combined measurement with 2 GeV error.

5 Conclusions

The CDF detector has essentially completed its commissioning phase by the end of year 2001 and has begun to collect data for RUN II. The detector performs as expected and first results will appear for Summer conferences in 2002.

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